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U.S. farmers' opinions on the use of nontraditional water sources for agricultural activities

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ABSTRACT

Water is a key resource for agricultural production in the United States. Due to projected changes in water availability across the country, long-term sustainability of agricultural production may rely on finding alternatives to traditional water sources. The aim of this study was to assess farmers' opinions on the use of nontraditional water sources (e.g., agricultural runoff, treated wastewater, recycled water, produced water, untreated surface water, and brackish surface and groundwater) for agricultural activities. A survey was distributed to farmers (n = 746) in the Mid-Atlantic and Southwest regions of the United States (U.S.) about water availability and nontraditional irrigation water perceptions. Chi-square, Fisher's exact tests, f-tests, and multinomial and ordinal logistic regression analyses were conducted. Of farmers surveyed, 80% (431/543) considered the use of nontraditional water sources to be at least moderately important and 61% (444/727) would use nontraditional water if given the option. Each of the following factors individually increased the likelihood that a farmer considered nontraditional water very important for agriculture: Farmers who lived in the Southwest region compared to the Mid-Atlantic, farmers who were concerned about water availability compared with those who were not, farmers with a graduate or professional degree compared to those with less education, farmers with access to nontraditional water, and farmers with some knowledge of nontraditional water compared to those with no reported knowledge. Concern about water availability and knowledge of nontraditional water sources were significantly associated with willingness to use these water sources ($p < 0.001$ for both). Water quality, food safety and health risks were the main concerns regarding nontraditional water use across both regions. Willingness to use nontraditional water increased significantly if the water quality was proven to be as good or better than farmers' current water sources (63% vs. 84%; $p < 0.001$). Projects focused on nontraditional water use in agriculture should be regionally tailored as our data found significant differences between farmers in two distinct U.S. regions.

1. Introduction

Agriculture is a critical economic sector in the United States (U.S.). Based on 2015 estimates, agriculture and food industries contributed 5.5% of the U.S. global domestic product, valued at $992 billion U.S. dollars (USDA ERS, 2018). A significant portion of this contribution comes directly from the 3.2 million farmers who operate over 2 million farms across the country (USDA NASS, 2014). Agricultural production relies heavily on natural resources, including water. Water is used in many aspects of agricultural production, including care of livestock, application of agro-chemicals, food safety and hygiene practices, and irrigation. The agricultural sector is the largest user of fresh water both globally (69%) and within the U.S. (36%) (FAO, 2016; Maupin et al., 2014). Of the estimated 915 million acres of farmland in the United States, just over 55 million acres are irrigated. Water is so important in agricultural production that increased water usage on a farm is positively associated with higher farmland value (Mendelsohn and Dinar, 2003). This reliance on water as an input makes the agricultural system

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vulnerable to changes in water availability (Mendelsohn and Dinar, 2003).

Water resource availability varies widely in the United States and projected future availability is also varied. In the Mid-Atlantic U.S., land cover includes urban and suburban development, forest, grasslands, coastal zones, beaches and dunes, and wetlands (Horton et al., 2014). This region has highly seasonal weather, with hot, often humid summers and cold winters. Precipitation is common year-round (Horton et al., 2014). Heavy precipitation events have increased by over 70% in the last few decades in the Mid-Atlantic region (Horton et al., 2014). The risk of seasonal drought and the risk of more frequent heavy precipitation are both projected to increase in the Mid-Atlantic (Horton et al., 2014). On the other side of the United States is the semi-arid Southwestern region, the hottest and driest region of the country (Garfin et al., 2014). The Southwestern U.S. is more mountainous, with desert and plateau land cover, grasslands, and some coastal and riparian zones (Garfin et al., 2014). Precipitation projections indicate a mix of increased and decreased precipitation across the Southwest region, but future temperatures will be substantially hotter and are expected to lead to more frequent, more intense, and longer-lasting droughts than in the past in major river basins (Garfin et al., 2014). Changes in water availability will affect regional agricultural production in both the Mid-Atlantic and Southwest U.S. in impactful but different ways (Walthall et al., 2012).

The agricultural industry has historically been successful at responding to environmental changes through technological innovations and improved water management (Garfin et al., 2014). Farmers have always needed to adapt to changes in the environment, consumer demand, and availability of natural resources (Bryant et al., 2000). Starting in the 1930's, and more rapidly since the 1970's, farmers around the world have adopted conservation technologies, including no- or low- till practices, in response to soil erosion (Verhulst et al., 2010; Farooq and Siddique, 2015). Irrigation technology has been an area of intense innovation starting in the mid-twentieth century, as farmers adopted new on-farm irrigation practices to conserve water and increase water use efficiency (Howell, 2000). Irrigated cropland, which makes up 25% of farmland in the Mid-Atlantic and 92% of all cropland in the Southwest, is particularly susceptible to drought (USDA NASS, 2014; Garfin et al., 2014; USDA NASS, 2018). Due to increasing environmental pressures, the long-term sustainability of irrigated agriculture requires additional innovation in high-efficiency irrigation systems and water management practices (Schaible and Aillery, 2012).

One important water management practice could be the adoption of nontraditional water sources for agricultural irrigation. Nontraditional water sources include agricultural runoff, treated wastewater, recycled water, produced water, untreated surface water, and brackish surface and groundwater. Utilizing these water sources is increasingly being explored as an adaptive strategy in response to climate change's impact on traditional irrigation sources, such as groundwater. Diversifying water sources available for agricultural irrigation is a United States Department of Agriculture (USDA) priority given the current and future challenges to agricultural water (USDA NIFA, 2017).

Adoption of nontraditional water for agricultural irrigation is dependent on buy-in from the farmers who would use these water sources. Understanding the opinions of farmers regarding nontraditional water use in agriculture is an important first step to inform research, education, and policy on nontraditional water sources, technologies, and practices.

To our knowledge, no previous studies have compared farmers' views on nontraditional irrigation water in agriculture across the United States. In this study, we used surveys to evaluate farmer perceptions of water availability, willingness to use nontraditional water for agricultural irrigation, and regional differences among farmers in two distinct regions of the U.S.: the Mid-Atlantic and the Southwest.

2. Materials and methods

This study is part of CONSERVE (COordinating Nontraditional Sustainable watER Use in Variable climatEs): A Center of Excellence at the Nexus of Sustainable Water Reuse, Food, and Health. CONSERVE is a USDA National Institute for Food and Agriculture funded project that focuses on conserving groundwater resources by investigating nontraditional sources of irrigation water for use on food crops eaten raw, such as fruits and vegetables. CONSERVE is assessing quality of these water sources, developing on-farm water treatment technologies, and analyzing legal, policy, economic and social constraints to adoption. CONSERVE is focused on the Mid-Atlantic and Southwest regions of the U.S. to gain insight into regions with different water cultures and water issues.

2.1. Study population, recruitment, and data collection

The Mid-Atlantic region was defined as Delaware, Washington, D.C., Maryland, Pennsylvania, Virginia, and West Virginia, per the states that make up the U.S. Environmental Protection Agency Region 3 (US EPA, 2018). Over 216,000 farmers resided in the Mid-Atlantic region as of 2012 (USDA NASS, 2014). The Southwest region was defined as Arizona, California, Colorado, Nevada, New Mexico, and Utah per the states that make up the Southwest Principal Aquifers (Thiros et al., 2014). In 2012, 317,550 farmers were recorded as living in the Southwest region (USDA NASS, 2014).

Using data from the United States National Climatic Data Center (National Oceanic and Atmospheric Administration, U.S. Department of Commerce), Figs. 1 and 2 were created with ArcGIS 10.3 (Redlands, CA, USA) to illustrate climatic trends in the study regions during the time the survey was distributed. Based on Precipitation Index (PCP) data, annual average precipitation in the Mid-Atlantic region was 94 mm/year between 2016 and 2018. The Southwest region had 32 mm/year of average precipitation, with California receiving 53 mm/year of average annual rainfall (Fig. 1). Over the same time period, drought conditions based on the Palmer Drought Severity Index (PDSI) in the Mid Atlantic were normal (Fig. 2). However, the Southwest region experienced a range of normal to moderate drought conditions, with the most severe drought occurring in Arizona over this same time period (Fig. 2). The Southwest is facing acute water shortage issues; whereas the Mid-Atlantic region faces potential future changes in water supply due to projected climate change impacts.

The survey was distributed from March 2016 through February 2018 in both study regions. Participants were recruited using a convenience sample in person and through online recruitment. The online survey was developed and stored on the survey platform Qualtrics (Qualtrics, Provo, Utah, USA). In both regions, researchers attended agricultural meetings, such as educational workshops, vegetable and fruit farmer meetings, and trade association meetings, to recruit meeting attendees to participate in the survey. The research team distributed the survey and followed a written script when recruiting respondents to take part in the study. Researchers sought informed consent orally and provided a written informed consent agreement to each participant. At in-person distribution events, participants were offered paper and electronic versions of the survey using electronic tablets provided by the reviewers. Depending on the technological options at each meeting, sometimes only paper or only electronic versions could be made available to the participants.

In addition, an online link to the survey was distributed to local partners in both regions, including Extension faculty, local agricultural leaders, and agriculturally-focused media outlets. The online survey was preceded by an informed consent agreement. These targeted partners were asked to distribute the link to their networks through email listservs, social media, or online newsletters.

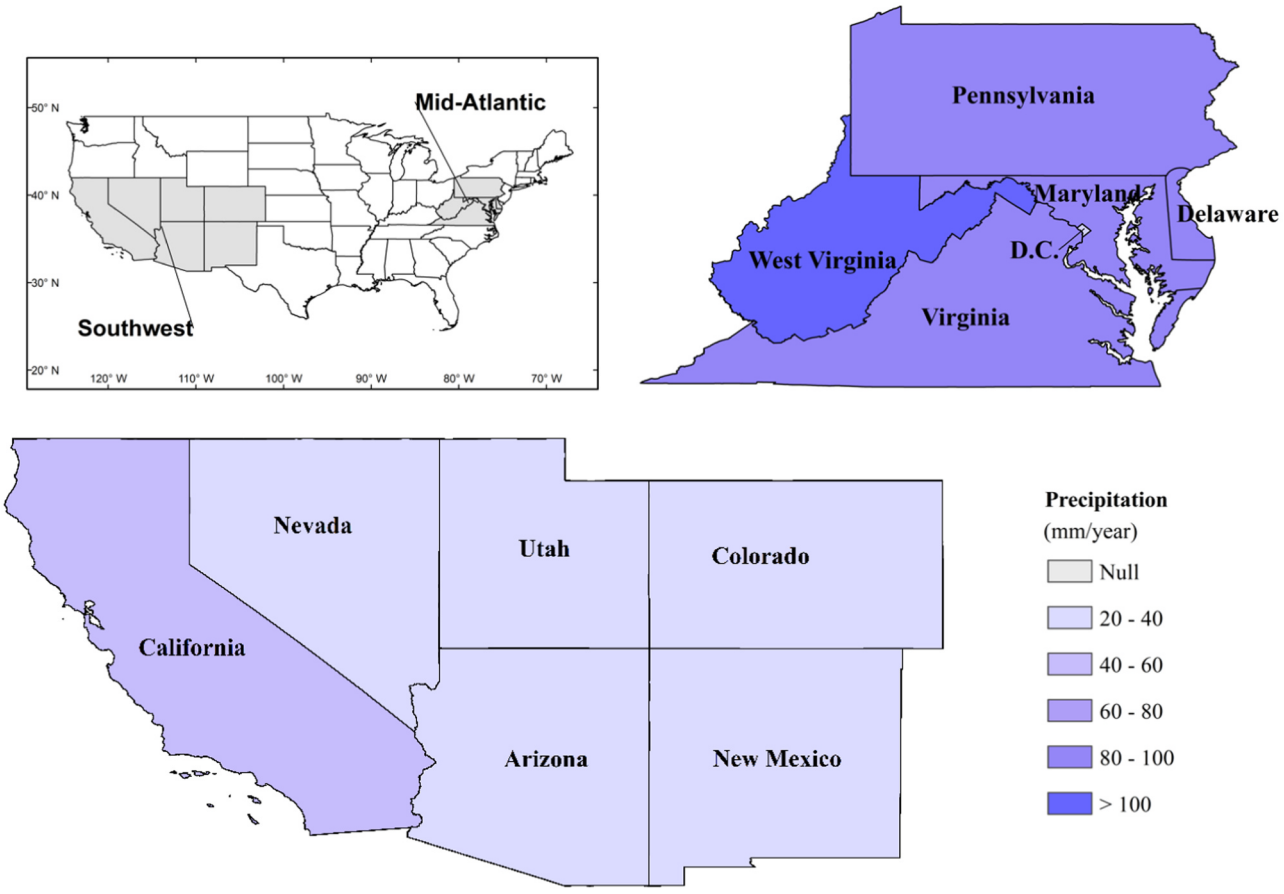

Fig. 1. Average annual precipitation in the Mid-Atlantic and Southwest United States from March 2016 to February 2018. Precipitation data was retrieved from the National Climatic Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

2.2. Survey instrument

The survey was developed as a collaborative effort between the University of Arizona Cooperative Extension and University of Maryland Extension with input from stakeholders including farmers, state regulators, water managers, county Extension agents, and Extension Specialists (Supplemental Table 1). The questions were drafted after a review of the literature related to similar stakeholder assessments as well as in collaboration with Extension educators. A similar survey had been used in a previous study of statewide public perceptions regarding water reuse in Arizona conducted by members of our team (Rock et al., 2012). This study was approved by the University of Maryland College Park, Institutional Review Board, IRB Protocol 960819-3.

Participants were asked to answer 22 multiple-choice and open-ended questions on their association with water, primary water source, current knowledge of nontraditional water sources, access to nontraditional water sources, opinions of nontraditional water sources—including opinions on use, concerns, willingness to pay, importance—and preferred education methods. Participants were also asked to provide demographic information and were given space to write any additional comments. Supplemental Table 1 displays all of the questions included in the survey. Participants were able to select more than one answer for the following questions: “For which activities would you be willing to use nontraditional water sources such as reclaimed water?,” “What are some of your concerns regarding the use of nontraditional water?,” “What would help alleviate your concerns regarding the use of nontraditional water sources?,” and “Which method of outreach/educational program would work best for you to learn more information about nontraditional water sources?”.

2.3. Statistical analyses

This paper focuses on participants’ responses to the survey questions including their association with water, primary water source, concern about water availability, knowledge of nontraditional water sources, opinions of nontraditional water sources, and demographic information. First, descriptive statistics were reported, such as the percentages of study participants that would be willing to supplement their current water source with nontraditional water by region. A test of means was conducted to determine if the mean values of the sociodemographic variables differed between survey respondents and total farmers in each region. Chi-square, Fisher's exact tests, and f-tests were used to compare differences in sociodemographic variables and responses related to nontraditional water and concerns between Mid-Atlantic and Southwest survey respondents. Regional comparison analyses focused on questions directly related to opinions on nontraditional water use in agriculture (questions 4, 5, 6, 7, 8, 9, 10, 12 on the survey – Supplemental Table 1). Additional analyses on “What is your willingness to pay to use nontraditional water if it was proven to have the same quality as your current water source?” (question 13) and questions related to education and outreach methods “What would help alleviate your concerns regarding the use of nontraditional water sources?”(question 11) and “Which method of outreach/educational program would work best for you to learn more information about nontraditional water sources?”(-question 14) will be undertaken in the future.

For the qualitative responses to questions “Why or Why not [would you use nontraditional water to supplement your current water source]?”, “What would help alleviate your concerns regarding the use of nontraditional water source – Other: Text Response”, and “If you have additional comments regarding this topic, please leave them

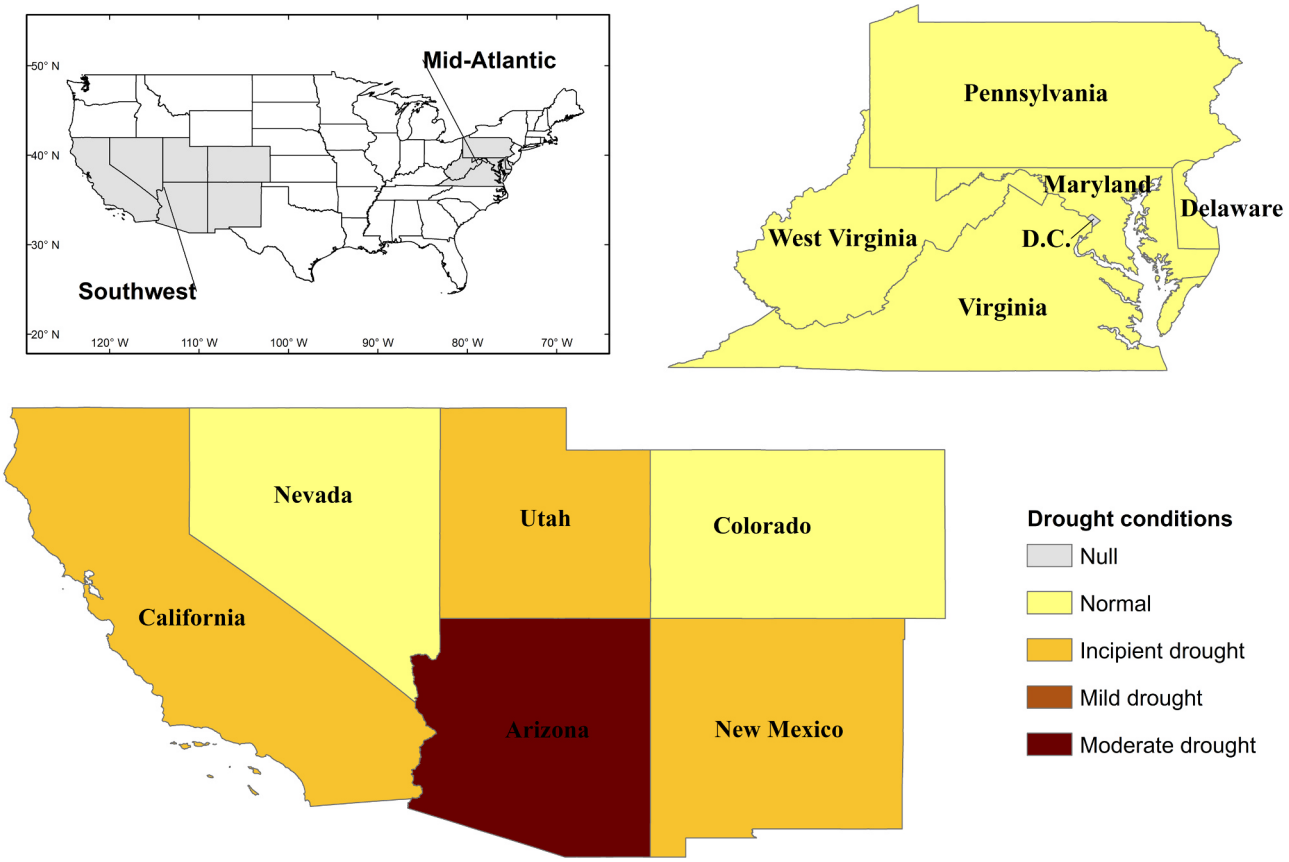

Fig. 2. Drought conditions based on the Palmer Drought Severity Index in the Mid-Atlantic and Southwest United States from March 2016 to February 2018. Palmer Drought Severity Index data was retrieved from the National Climatic Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

here", responses were coded to fit into the following categories: consumer satisfaction, food safety and health risk, other, reliability of treatment methods, water quality, water quantity, and water salinity. Coding was completed by a research team member and then reviewed by a second trained researcher. Data from the qualitative responses was combined with responses to question 10 (Concerns) to create Fig. 5.

A multinomial logistic regression model was used to estimate the Relative Risk Ratio (RRR) of being willing to supplement current irrigation water sources with nontraditional water. Independent variables in this multinomial logistic regression model included region, level of concern about water availability, primary water source, age, sex, race, ethnicity, education, farm size, access to nontraditional water sources, and knowledge about nontraditional water. There were three outcome variables for farmers' willingness to supplement their current water source with nontraditional water: "yes", "no", and "I don't know". Only the estimated RRR for "yes" vs. "no" are presented in the results section (Table 4).

Ordinal logistic regression models were used to examine various factors associated with the level of importance of nontraditional water sources and level of water availability concern. The model to test the importance of nontraditional water in agriculture included region, water availability concern, primary water source, age, sex, race, ethnicity, education, farm size, access to nontraditional water sources, and knowledge about nontraditional water as predictor variables. The outcome variables for the level of importance of nontraditional water in agriculture were: "very important", "moderately important", and "not important". The model compared farmers who responded that the importance of nontraditional water in agriculture was "very important" to those who responded that it was "moderately important" or "not important". The model to test water availability concern included region, primary water source, age, sex, race, ethnicity, education, and farm size as predictor variables. The outcome variables for water availability concern were: "yes", "no", and "somewhat". The response category "I don't know" was dropped for water availability concern due to sparsity of data (only four respondents answered using the "I don't know" category). The results were interpreted using odds ratio (OR) estimates and 95% Confidence Intervals (CIs) for both ordinal logistic regression models.

In all cases, p-values of ≤ 0.05 were defined as statistically significant. All statistical analyses were performed using Stata/IC 15 (StatCorp LP, College Station, TX, USA) or SAS Studio Release 3.7 (Enterprise Edition) (Cary, NC, USA).

3. Results

Of the total 887 participants who completed the survey, 746 reported residing in the two U.S. regions of interest, the Mid-Atlantic (n = 269) and the Southwest (n = 477). Researchers analyzed responses from the regions of interest only.

3.1. Farmer demographics

Survey respondents were predominantly white, non-Hispanic males between 50 and 69 years old with at least a 2-year post-high school degree (Table 1). Farmers differed by region on age, sex, race, and ethnicity, but had similar levels of education.

Most Mid-Atlantic (63%, n = 162) and Southwest respondents (66%, n = 169) farmed between 0 and 100 acres. In the Southwest, more farmers reported farming 1001 to over 2000 acres (Table 1). Mid-Atlantic survey respondents were similar to overall Mid-Atlantic

Table 1
Respondent demographics for a survey on nontraditional water sources for agricultural irrigation.

Variable	n (%) Region			*p*-value
	Mid-Atlantic	Southwest	Total	
Age (years)				< 0.001
18–29	17 (7)	83 (31)	100 (19)	
30–49	86 (33)	95 (35)	181 (34)	
50–69	135 (52)	80 (30)	215 (41)	
70–89	19 (7)	11 (4)	30 (6)	
Total	257	269	526	
Sex				0.03
Female	77 (31)	108 (40)	185 (36)	
Male	173 (69)	162 (60)	335 (64)	
Total	250	270	520	
Ethnicity				< 0.001
Hispanic or Latino	8 (3)	70 (28)	78 (16)	
Not Hispanic or Latino	221 (97)	179 (72)	400 (84)	
Total	229	249	478	
Education				0.14
Some college or less	108 (41)	92 (34)	200 (37)	
2-year degree	9 (3)	17 (6)	26 (5)	
4-year degree	89 (34)	98 (36)	187 (35)	
Graduate or professional degree	54 (21)	61 (22)	115 (22)	
Doctorate	1 (0)	5 (2)	6 (1)	
Total	261	273	534	
Race				0.03
White	222 (85)	208 (76)	430 (81)	
Black/African-American	7 (3)	4 (1)	11 (2)	
Other	4 (1)	16 (6)	20 (4)	
I prefer not to answer	28 (11)	44 (16)	72 (13)	
Total	261	272	533	
Farm Size (acres)				< 0.001
0–100	162 (63)	169 (66)	331 (64)	
101–1000	83 (32)	34 (13)	117 (23)	
1001-over 2000	14 (5)	53 (21)	67 (13)	
Total	259	256	515	

farmers on all sociodemographic variables collected ($p \leq 0.02$), except that a higher percentage of females responded to the survey (31%) than are in the total farmer population in the region (15%). Southwest survey respondents differed from overall Southwest farmers on all sociodemographic variables collected ($p \geq 0.05$), except for the percentage of African American farmers.

3.2. Survey responses and regional comparison

The Southwest and Mid-Atlantic farmers differed significantly on most demographic variables as reported above (Table 1), and many of the questions related to nontraditional water use as detailed below (Table 2).

Participants were asked to select their primary water source (question 2 in Supplemental Table 1). As displayed in Table 2, half of all participants reported using surface water as their primary water source (50%, n = 366). But between the two regions, the primary water source was significantly different ($p < 0.001$). In the Mid-Atlantic, groundwater was reported as the primary water source (59%, n = 157) and in the Southwest, surface water is the primary water source (61%, n = 286). Additionally, 1% (n = 2) of Mid-Atlantic farmers and 2% (n = 11) of Southwestern farmers reported using reclaimed water as the primary water source on their farms.

A majority of all respondents were at least somewhat concerned about water availability (76%, n = 382). However, there were significant regional differences in concerns about water availability: 66% (n = 145) of Mid-Atlantic farmers responded that they are at least somewhat concerned about water availability compared to 84% (n = 237) of Southwest farmers ($p < 0.001$) (Table 2). Across both study regions, most respondents reported having a little knowledge (39%, n = 288) or being somewhat knowledgeable about nontraditional water (33%, n = 241). Only 11% (n = 79) of respondents reporting being very knowledgeable about nontraditional water (Table 2). Current levels of knowledge differed between the study regions ($p < 0.001$) and was most apparent in the percentage of farmers responding that they have no current knowledge about nontraditional water; 29% in the Mid-Atlantic (n = 78), 11% in the Southwest (n = 53).

Despite relatively low levels of reported knowledge, most respondents (80%, n = 431) considered the use of nontraditional water sources in agriculture to be at least moderately important, with significant variation between the regions ($p < 0.01$). More Southwestern farmers (47%, n = 131) considered nontraditional water in agriculture very important than their Mid-Atlantic counterparts (23%, n = 62) ($p < 0.01$) (Table 2).

Seventy-nine percent of farmer respondents (n = 387) responded that they either did not have access to nontraditional water sources or did not know if they have access; this was the only question on the survey related to nontraditional water sources that was the same across both regions ($p = 0.08$) (Table 2).

When asked to select activities for which respondents would be willing to use nontraditional water, irrigation for vegetables, fruits, and nuts was the top selection in the Mid-Atlantic (61%, n = 158) and third in the Southwest (42%, n = 207) (Fig. 3). The top choice in the Southwest was dust control near produce fields (62%, n = 302). The proportion of Mid-Atlantic and Southwest farmers' willing to use nontraditional water differed significantly for all activities ($p \leq 0.01$), except for irrigation of orchards ($p = 0.69$), produce washing ($p = 0.07$), and hand washing ($p = 0.36$).

Most respondents reported that they would use nontraditional water to supplement their current water source if given the option (61%, n = 444), with Southwestern farmers being more willing to use this water source (66%, n = 307) compared to Mid-Atlantic farmers (52%, n = 137) ($p < 0.01$) (Table 2). Notably, there was a significant increase in the percentage of farmers willing to supplement their current water source with nontraditional water if the water quality was proven to be as good or better than their current water sources (Fig. 4) ($p < 0.001$).

For farmers concerns about nontraditional water, both the multiple choice and open-ended responses were included to create Fig. 5. As shown in Fig. 5a and b, the most common concerns in both the Mid-Atlantic and Southwest regions about using nontraditional water sources were water quality (Mid-Atlantic 28%, n = 234; Southwest 28%, n = 381) and food safety and health risks (Mid-Atlantic 19%, n = 155; Southwest 19%, n = 255). The only statistically significant difference between the two study regions in terms of farmer concerns regarding nontraditional water use was customer satisfaction ($p < 0.001$), with 4% of farmers in the Mid-Atlantic (n = 37) and 9% of farmers in the Southwest (n = 122) responding that customer satisfaction was a concern.

3.3. Association analyses

Chi-square or Fisher exact tests were used to determine if factors included in the survey were associated with farmers being concerned about water availability, considering nontraditional water in agriculture important, and being willing to supplement current water sources with nontraditional water sources. Farmers' water availability concerns were significantly associated with their region of residence ($p < 0.001$), but not their current primary water source ($p < 0.09$). Farmers' responses to the importance of nontraditional water sources in agriculture were significantly associated with region of residence ($p < 0.001$), water availability concern ($p < 0.001$), and current level of knowledge about nontraditional water ($p < 0.001$), but not their

Table 2
Farmer responses to survey on nontraditional water sources for agricultural irrigation.

	n (%) Region			*p*-value
	Mid-Atlantic	Southwest	Total	
Primary water source				< 0.001
Surface water	80 (30)	286 (61)	366 (50)	
Groundwater	157 (59)	147 (31)	304 (41)	
Reclaimed water	2 (1)	11 (2)	13 (2)	
Other	28 (10)	27 (6)	55 (7)	
Total	267	471	738	
Concern about water availability				< 0.001
Yes	79 (36)	186 (66)	265 (53)	
No	69 (32)	43 (15)	112 (22)	
Somewhat	66 (30)	51 (18)	117 (23)	
I don't know	3 (1)	1 (0)	4 (1)	
Total	217	281	498	
Knowledge of nontraditional water sources				< 0.001
Very knowledgeable	16 (6)	63 (13)	79 (11)	
Somewhat knowledgeable	61 (23)	180 (38)	241 (33)	
A little knowledgeable	113 (42)	175 (37)	288 (39)	
No current knowledge	78 (29)	53 (11)	131 (18)	
Total	268	471	739	
Importance of nontraditional water				< 0.001
Very important	62 (23)	131 (47)	193 (36)	
Moderately important	11 (45)	119 (43)	238 (44)	
Not important	83 (31)	29 (10)	112 (21)	
Total	264	279	543	
Access to nontraditional water				0.08
Yes	53 (25)	51 (18)	104 (21)	
No	120 (56)	150 (54)	270 (55)	
I don't know	42 (20)	75 (27)	117 (24)	
Total	215	276	491	
Would supplement with nontraditional water				< 0.001
Yes	137 (52)	307 (66)	444 (61)	
No	38 (14)	77 (17)	115 (16)	
I don't know	88 (33)	80 (17)	168 (23)	
Total	263	464	727	
Would supplement with nontraditional water if quality was as good or better than current source				< 0.001
Yes	198 (75)	391 (84)	589 (81)	
No	15 (6)	18 (4)	33 (5)	
Maybe	11 (4)	31 (7)	42 (6)	
I don't know	39 (15)	24 (5)	63 (9)	
Total	263	464	727	

current primary water source ($p = 0.43$). Farmers' willingness to supplement their current water sources with nontraditional water was significantly associated with region of residence ($p < 0.001$), water availability concern ($p < 0.001$), current level of knowledge about nontraditional water ($p < 0.001$), but not their current primary water source ($p = 0.18$). Significant associations between concern about water availability and reported knowledge of nontraditional water sources with willingness to supplement current water sources with nontraditional water are displayed in Fig. 6.

3.4. Ordinal logistic regression model: water availability concern

The ordinal logistic regression model that analyzed the impact of region, water availability concern, primary water source, age, sex, race, ethnicity, education, farm size, access to nontraditional water sources, and knowledge about nontraditional water on concern about water availability identified two factors that increased the odds of being concerned with water availability: region and age. The odds of being concerned with water availability versus being less concerned (e.g., somewhat and not concerned) were 4.3 times higher for Southwestern farmers than for Mid-Atlantic farmers (OR = 4.3; 95% CI = 2.59, 7.15) (Table 3). When looking at age across both regions, 50–69-year-old farmers were more likely to be concerned about water availability compared to 18–29 year-olds (OR = 2.13, 95% CI = 1.14, 3.99) (Table 3).

3.5. Ordinal logistic regression model: importance of nontraditional water sources in agriculture

The ordinal logistic regression model identified five factors that increased the odds of considering nontraditional water in agriculture as very important versus moderately and not important (Table 3): 1) Southwest farmers compared to Mid-Atlantic farmers, 2) farmers who were concerned about water availability compared to farmers not concerned about water availability, 3) farmers who had a graduate/professional degree compared to those with less than 2 years of college, 4) farmers who had access to nontraditional water sources compared to those who did not have access, and 5) farmers who self-reported as being a little or somewhat knowledgeable about nontraditional water compared to those who had no knowledge about nontraditional water (Table 3).

Southwestern farmers were more likely than Mid-Atlantic farmers to consider nontraditional water very important versus less important (e.g., moderately and not important) (OR = 3.29; 95% CI = 1.87, 5.79). Farmers who were concerned about water availability were more likely to consider nontraditional water very important rather than less

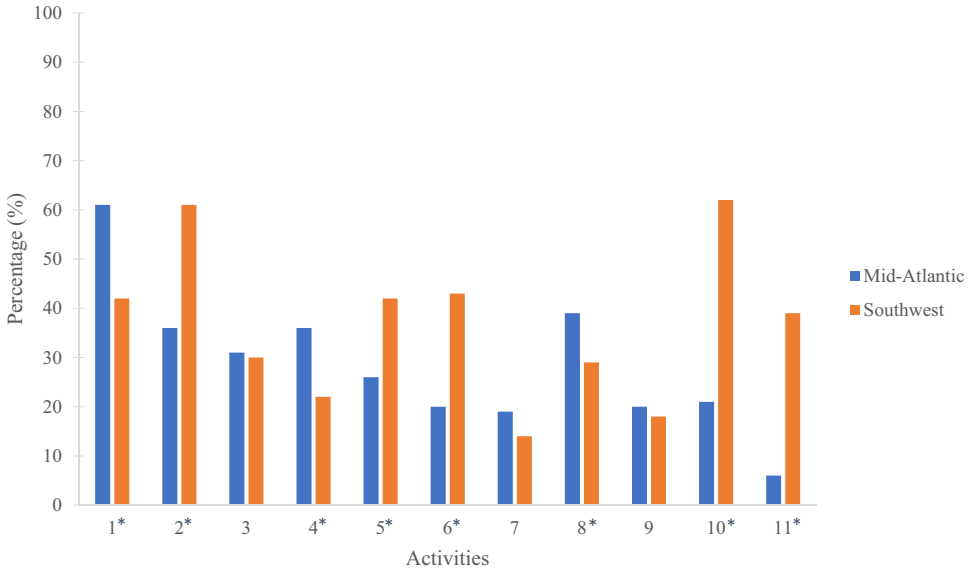

Fig. 3. Farmers responses to which activities they would be willing to use nontraditional water. (Respondents could select more than one response to the question about which activities they would be willing to use nontraditional water). *Indicates a statistically significant difference in the respondents who marked the choice as a concern between the Mid-Atlantic and Southwest farmers.

Legend

1 – Irrigation of field food crops (vegetables, fruits, nuts, etc.)
2 – Irrigation of field forage crops (wheat, gran, barley, etc.)
3 – Irrigation of orchards
4 – Irrigation of greenhouse/nursery-grown produce
5 – Irrigation of greenhouse/nursery-grown horticulture and/or ornamentals
6 – Produce production cooling/heating
7 – Produce washing
8 – Equipment wash water
9 – Hand washing
10 – Dust control near produce fields
11 – Other

important (e.g., moderately and not important) (OR = 2.49; 95% CI = 1.37, 4.52). Farmers with a graduate or professional degree compared to those with less than two years of college education were more likely to consider nontraditional water very important over less important (e.g., moderately and not important) (OR = 2.08; 95% CI = 1.08, 4.00). Farmers who reported having access to nontraditional water sources compared to those with no access had higher odds of considering nontraditional water very important versus less important (e.g., moderately and not important) in agriculture (OR = 4.97, 95% CI = 2.66, 9.31). Farmers who reported a little knowledge of nontraditional water (OR = 2.49, 95% CI = 1.32, 4.67) and those who were somewhat knowledgeable (OR = 4.3, 95% CI = 2.12, 8.73) compared to those who reported no knowledge were also more likely to consider nontraditional water very important versus less important (e.g., moderately and not important) (Table 3). Farmers who primarily used surface water versus groundwater were less likely to consider nontraditional water very important versus less important (e.g., moderately and not important) (OR = 0.52; 95% CI = 0.32, 0.85).

3.6. Multinomial logistic regression model: willingness to supplement current water source with nontraditional water

The multinomial logistic regression model identified three factors that increased the relative risk of being willing to supplement current water sources with nontraditional water versus not being willing to supplement with nontraditional water (Table 4): 1) importance of nontraditional water sources in agriculture, 2) sex, and 3) race (Table 4). Farmers who perceived nontraditional water as moderately or very important (RRR = 7.42, 95% CI = 1.8, 30.55; RRR = 22.79, 95% CI = 3.53, 147.13) were more willing to supplement current water sources with nontraditional water versus farmers who did not perceive it as important (Table 4). White respondents and female respondents were more willing to supplement with nontraditional water sources compared to black/African-American farmers (RRR = 0.05; 95% CI = 0.003, 0.8), farmers of other races (RRR = 0.05, 95% CI = 0.006, 0.37), and male farmers (RRR = 0.14, 95% CI = 0.26, 0.78). Surface water users were marginally more willing to supplement with nontraditional water compared to groundwater users (RRR = 3.05, 95% CI = 0.91, 10.18), although the results were not significant (Table 4).

3.7. Qualitative responses

In response to the open-ended survey questions, farmers expressed a range of opinions about using nontraditional water. These views ranged from acceptance to uncertainty to rejection. As shown in Table 5, a majority of farmers reported ambivalence or contingent support for nontraditional water sources, as opposed to acceptance or rejection. Many farmers commented that they needed more information before making a decision, some specifying the type of information they wanted, such as water quality and food safety impacts (Table 5). Their reported opinions on nontraditional water sources were mostly positive, but many concerns about economics, safety, food safety, access, water quality, and consumer perception remained (Table 5; Fig. 5). The farmers were motivated by personal beliefs such as “recycled water would appeal to us on an environmental level,” economic concerns such as “[I] would not consider using nontraditional water unless it becomes preferred by buyers of my lettuce,” and regulatory concerns such as “as long as FSMA [U.S. FDA Food Safety Modernization Act] approved.” Another common response was concern over food safety impacts such as “food safety is of paramount concern on my farm.” Select responses are presented in Table 5.

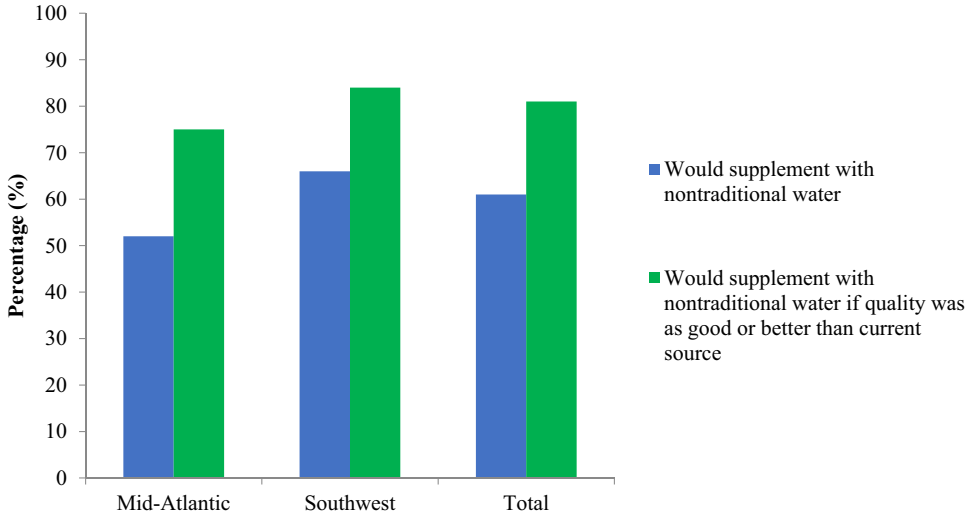

Fig. 4. Impact of water quality information on willingness to use nontraditional water sources among farmers.

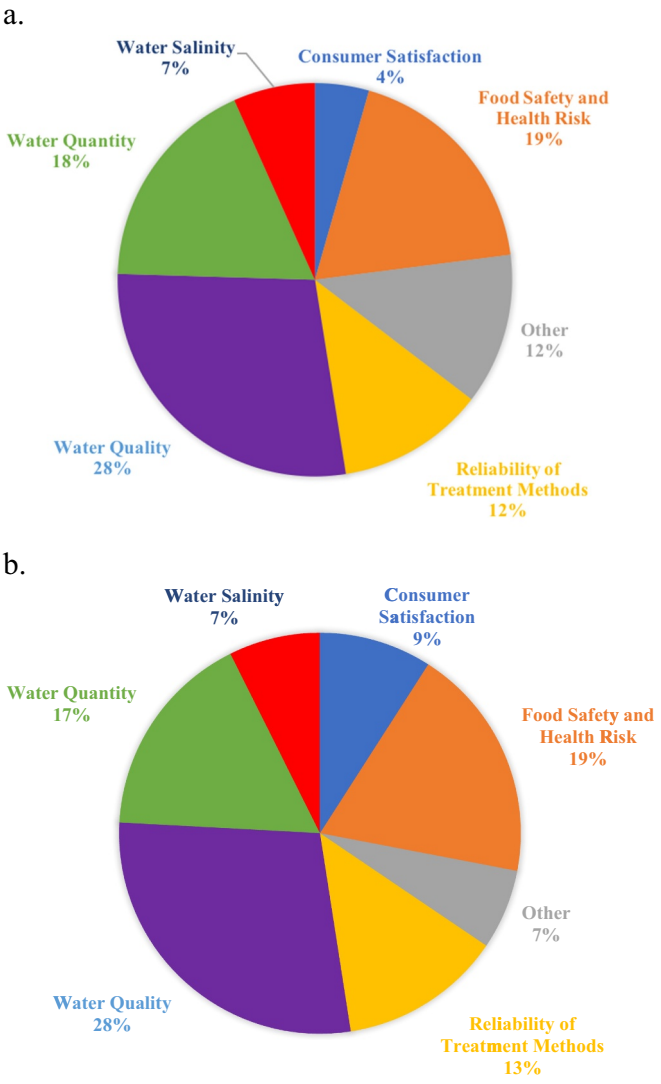

Fig. 5. Concerns regarding nontraditional water use among (a) Mid-Atlantic farmers and (b) Southwestern farmers.

4. Discussion

4.1. Impact of sociodemographic factors on water conservation practices

Our study found significant regional differences in sociodemographic factors and their impact on water availability concerns, opinions about the importance of nontraditional water, and reported willingness to adopt nontraditional water use (Tables 1 and 2). Studies that seek to determine why farmers adopt conservation practices have shown that a variety of sociodemographic and other factors, including farm size, education level, values, and attitudes affect these decisions (Knowler and Bradshaw, 2007). The impact of these factors also changes based on geographic region (Knowler and Bradshaw, 2007). In a review of 55 studies conducted in the United States, Prokopy et al. (2008), found that education levels, capital, income, farm size, access to information, attitude, and social networks usually positively impacted adoption of conservation practices among farmers. Rubas (2004) measured adoption of technology in general, not water conservation specifically, among U.S. farmers and found a weak positive correlation for both farm size and farmer education level.

Our ordinal logistic model also found that female respondents were more willing to supplement their current water source with nontraditional water sources (Table 3). There is some evidence that women are more willing to engage in some types of environmentally protective behaviors. Irwin et al. (2015) found that compared with men, women are more likely to engage in environmentally-protective behaviors in the private sphere – that is, actions that can be taken at a personal or household level as opposed to actions requiring political action. Since farm management decisions about water sources can be taken by the farm operator, this proclivity toward environmentally-protective action may explain our finding that women are more willing than men to use nontraditional water sources.

Our ordinal logistic regression model determined that farmers had higher odds of considering nontraditional water very important versus not important if they had a graduate or professional degree compared to those with less than two years of college (Table 3). However, the multinomial regression model did not find any significant increased likelihood of willingness to supplement with nontraditional water with higher education levels (Table 4). Similar to the Prokopy et al. (2008) review, our results found that access to information on nontraditional water quality significantly increased the willingness to use it on the

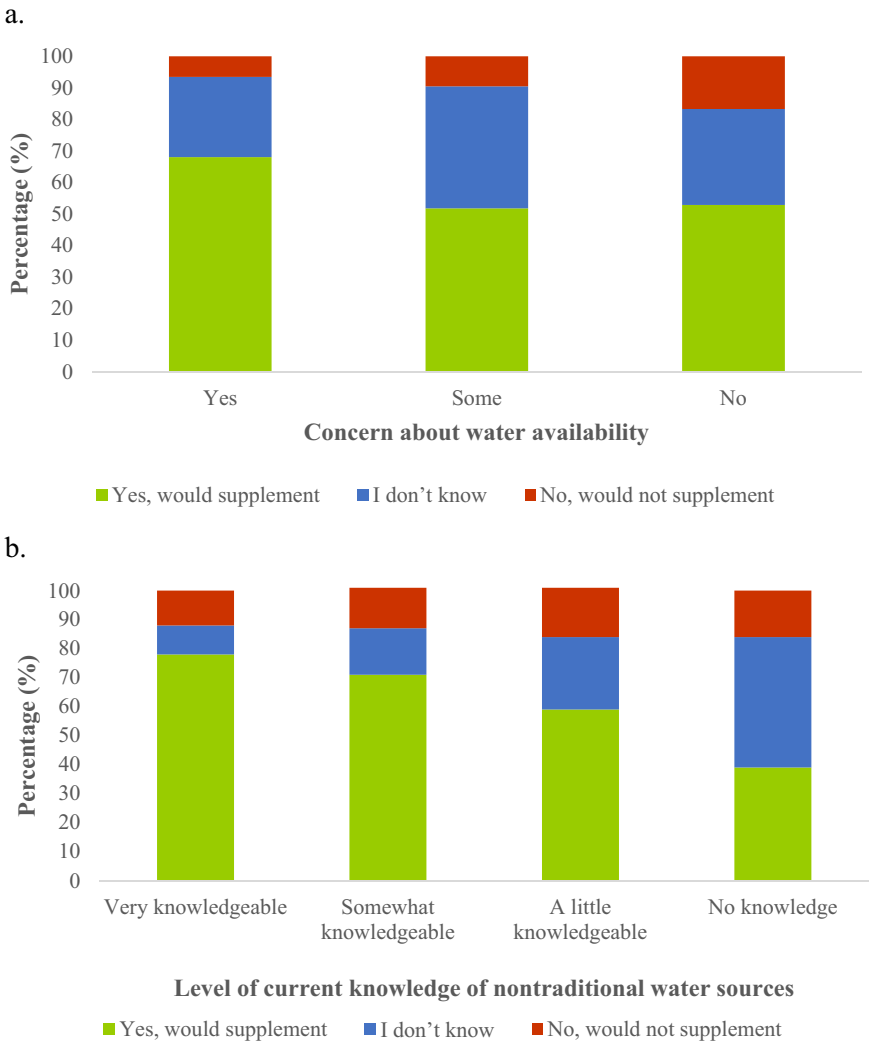

Fig. 6. Association of (a) water availability concern and (b) current knowledge of nontraditional water with farmers' willingness to supplement current water sources with nontraditional water.

farm in both regions. Additionally, farmers in the current study were more likely to consider nontraditional water sources in agriculture very important versus less important (e.g., moderately and not important) if they were a little or somewhat knowledgeable about nontraditional water versus having no knowledge (OR = 2.49, $p = 0.01$; OR = 4.3, $p < 0.001$). It is interesting to note that in our study, education level and reported knowledge of nontraditional water sources had different impacts on willingness to use those water sources.

Studies specifically measuring water use behavior changes in farmers are limited, especially in developed countries (Prokopy et al., 2008). Studies on residential water use behaviors may provide insight into what compels water users to change their behaviors. In the current study, a significant positive association was found between reported knowledge of nontraditional water sources and willingness to use them. Adams et al. (2013) found that in addition to knowledge, resident attitudes about governance, the environment, and information sources, demographic characteristics, and other values are also crucial drivers of residential water behaviors.

Farm income was not captured in the current study, but literature about consumer water attitudes has shown that income may be linked with acceptance of nontraditional water sources. Rock et al. (2012) found that the education level of Arizona consumers was positively linked with acceptance of recycled water use, a type of nontraditional water. Possession of a graduate or professional degree among farmers in the current study increased the odds that they considered nontraditional water in agriculture very important, but did not significantly impact the likelihood that they would be willing to use nontraditional water. Consumers with higher income levels were also significantly more accepting of recycled water in the Rock et al. (2012) study. This points to the need for further studies on different parameters, including farm income, and their impacts on farmer opinions of nontraditional water sources.

4.2. Regional differences

Although the majority of farmers in the Mid-Atlantic and Southwestern regions were at least somewhat concerned about water availability and were open to supplementing their current water sources with nontraditional water, there were significant regional differences in every question asked about nontraditional water use, except for accessibility ($p = 0.08$). In addition, living in the Southwest region was a significant factor in the increased likelihood of being concerned about water availability (OR = 4.3; 95% CI = 2.59, 7.15) and perceiving nontraditional water use as very important (OR = 3.29; 95% CI = 1.87, 5.79) in our ordinal logistic regression analyses. The reported high importance of nontraditional water in agriculture and openness to using this water source in the Southwest U.S. could be the result of the more frequent use of reclaimed water in this region (e.g.

Table 3
Factors explaining water availability concerns and the level of importance of nontraditional water in agriculture among farmers from ordinal logistic regression models.

Dependent variable	Explanatory variable	Odds ratio	*p*-value	95% confidence interval
Water availability concern[a]				
	Region			
	Mid-Atlantic	Reference		
	Southwest	4.3	< 0.001	2.59, 7.15
	Primary water source			
	Groundwater	Reference		
	Surface water	0.99	0.98	0.63, 1.57
	Reclaimed water	1.24	0.77	0.29, 5.31
	Other	1.15	0.76	0.49, 2.70
	Age			
	18–29	Reference		
	30–49	1.58	0.15	0.85, 2.95
	50–69	2.13	0.02	1.14, 3.99
	70–89	1.35	0.58	0.47, 3.91
Importance of nontraditional water[b]				
	Region			
	Mid-Atlantic	Reference		
	Southwest	3.29	< 0.001	1.87, 5.79
	Primary water source			
	Groundwater	Reference		
	Surface water	0.52	0.01	0.32, 0.85
	Reclaimed water	0.95	0.95	0.19, 4.67
	Other	0.18	0.18	0.76, 4.66
	Water availability concern			
	No	Reference		
	Some	1.37	0.36	0.71, 2.65
	Yes	2.49	0.003	1.37, 4.52
	I don't know	0.57	0.72	0.03, 12.22
	Knowledgeable about nontraditional water			
	No	Reference		
	A little	2.49	0.01	1.32, 4.67
	Somewhat	4.30	< 0.001	2.12, 8.73
	Very	2.24	0.09	0.88, 5.70
	Access to nontraditional water			
	No	Reference		
	Yes	4.97	< 0.001	2.66, 9.31
	I don't know	1.01	0.98	0.58, 1.77
	Education			
	Less than 2 years of college	Reference		
	2 years of college	1.78	0.26	0.66, 4.82
	4 year college degree	1.12	0.69	0.66, 1.90
	Graduate/professional degree	2.08	0.03	1.08, 4.00
	Doctorate	4.16	0.15	0.59, 29.45

[a] Controlled for race, sex, ethnicity, education, and farm size.
[b] Controlled for age, race, sex, ethnicity, and farm size.

landscape irrigation, toilet flushing, power generation) as well as the more arid climate and limited water resources compared to the Mid-Atlantic. Our findings support conclusions in the literature that water conservation and other climate adaptation strategies for the agricultural sector must be tailored based on regional realities and cultural differences (Hatfield et al., 2014). Further study is needed to explore which specific factors within a region most influence farmer water availability concerns as well as adaptive water use behavior.

4.3. Impacts of water availability concern on willingness to use nontraditional water

In this study, moderate to high concern about water availability was associated with willingness to supplement current water sources with nontraditional water sources ($p < 0.001$) as well as increased odds of considering nontraditional water in agriculture very important versus less important (e.g., moderately and not important) (OR = 2.5; 95% CI = 1.37, 4.52). Of farmers who were concerned about water availability, 68% were willing to supplement with nontraditional water compared to 53% who were not concerned (Fig. 6). In California, Dinar et al. (2017) found that farmers' choice of water management practices was driven by their perceptions of water scarcity. This is also consistent with findings that farmers who perceived risk at higher levels than average tended to have higher levels of support for adaptation (Arbuckle et al., 2015).

4.4. Farmer concerns about nontraditional water sources

Farmers in our study were most concerned about water quality and health risks posed by nontraditional water use (Fig. 5). There are few studies on farmer concerns related to nontraditional water, such as reclaimed water, and none in developed countries. International studies on farmer attitudes toward reclaimed water indicated mixed attitudes that acknowledged the benefits of reclaimed water, but also highlighted concerns (Carr et al., 2011; Sheidaei et al., 2016). Sheidaei et al. (2016) found that farmers in Iran had positive perceptions about the quantity and fertilizing quality of reclaimed water but were concerned about negative health and environmental impacts. This is similar to the concerns of farmers in this study with 28% of all respondents expressing concern about water quality and 19% expressing concern about food safety and health risks. Farmer comments from the current study also indicate that a wide range of factors affect perceptions of nontraditional irrigation water. This includes cost and other economic concerns, personal beliefs about the importance of water conservation, and concern

Table 4
Factors explaining the likelihood of farmers' willingness to supplement their current water source with nontraditional water compared to not supplement their current water source with nontraditional water from multinomial logistic regression model.[a]

Explanatory variable	Relative risk ratio	*p*-value	95% confidence interval
Region			
Mid-Atlantic	Reference		
Southwest	0.71	0.643	0.17, 2.97
Primary water source			
Groundwater	Reference		
Surface water	3.05	0.07	0.91, 10.18
Reclaimed water[b]			
Other	0.68	0.75	0.07, 4.49
Water availability concern			
No	Reference		
Some	1.13	0.87	0.27, 4.8
Yes	1.75	0.4	0.47, 6.52
I don't know[b]			
Knowledgeable about nontraditional water			
No	Reference		
A little	1.91	0.44	0.38, 9.66
Somewhat	0.46	0.35	0.09, 2.38
Very	1.11	0.93	0.12, 10.30
Importance			
Not important	Reference		
Moderately important	7.42	0.005	1.80, 30.55
Very important	22.79	0.001	3.53, 147.13
Access to nontraditional water			
No	Reference		
Yes	1.67	0.49	0.4, 7.05
I don't know	1.37	0.69	0.29, 6.50
Race			
White	Reference		
Black	0.05	0.03	0.003, 0.8
Other	0.05	0.004	0.006, 0.37
Sex			
Female	Reference		
Male	0.14	0.03	0.26, 0.78

[a] Controlled for age, ethnicity, education, and farm size.
[b] Variable not included because of data sparsity.

about food safety impacts (Table 5). Sheidaei et al. (2016) also found that a complex set of factors, such as knowledge, closeness to wastewater canals, and personal values, affected farmer perceptions of reclaimed water. Carr et al. (2011) found that Jordanian farmers using reclaimed water were concerned about salinity buildup, introduction of pests and/or pathogens, and potential physical damage to their irrigation systems, such as clogged pipes. Additional studies in more U.S. regions, and more detailed studies of why farmers have these concerns, are needed.

4.5. Study limitations

Due to the small, nonrandom and non-representative population sample, these findings cannot be generalized to the broader U.S. farmer population. Future study may be improved by using a random, larger sample. However, as the first comparative study of farmer opinions of nontraditional water use between unique regions, the results of this study do provide helpful insights for future research and outreach related to nontraditional water use.

4.6. Areas for further study

As this is among the first studies to capture and compare U.S. farmer opinions of nontraditional water sources in different U.S. regions, there are many areas that warrant additional study. A major area for future analysis is the economic aspect of nontraditional water use, such as how water pricing, changes in commodity prices, farm income, and commodities grown, affect opinions on nontraditional water use. Another important area for future study is attitudes about adoption of nontraditional water sources as a climate change adaptation strategy.

5. Conclusions

This is the first study to compare farmer perceptions regarding nontraditional irrigation water use for agriculture between regions of the United States. Most farmers in both the Southwest and Mid-Atlantic regions of the U.S. have concerns about water availability and are willing to use nontraditional water to supplement their current irrigation water sources. Results indicate farmers' willingness to supplement current water supplies with nontraditional water sources would increase if nontraditional water could be proven to be of similar or better quality than their current source, if farmers had some knowledge related to this water source, or if they were concerned about water availability. Significant regional differences emphasize the need for localized approaches to address projected changes in agricultural water resources, including the use of nontraditional water sources for agricultural irrigation. Given the global magnitude but regionally-specific consequences of projected climate change impacts, innovation and

Table 5
Select responses from open-ended questions on farmer needs assessment survey related to nontraditional water use.

a. Responses to the question: "Why would or wouldn't you supplement your irrigation water with nontraditional water sources?"

Supplement your irrigation water with nontraditional water sources?	Comment	State of residence
Would	We need to protect our water sources.	Arizona
Would	As long as FSMA [Food Safety Modernization Act] approved	Arizona
Would	If the water is clean and safe, it should be used, every drop count	California
Would	If it's treated to proper standards it shouldn't matter what the source is.	Colorado
Would	I think it is necessary to consider all options for water use to prevent future water supply issues.	Maryland
Would	The over use of water is a national problem. We need to learn to think of other ways.	Maryland
Would	If it would be convenient to integrate into our production and would yield exponential useful. We would consider it.	Maryland
Would not	Fear of reliability and quality	Arizona
Would not	I am concerned about consistency of quality and long-term effects of non-removable contaminants i.e.: metals, pharmaceuticals.	Arizona
Would not	I have enough water at this point	Maryland
Would not	Not needed at this time	Pennsylvania
Would not	I don't know about the safety of using nontraditional water for my animals.	Maryland

b. Responses to the question: "What would help alleviate your concerns regarding the use of nontraditional water sources?"

Comment	State of residence
Positive perceptions from the general public is the #1 problem	Arizona
Educating the public private sector, all stakeholders	Arizona
Maryland GAP approval through Maryland Department of Agriculture	Maryland
Comprehensive testing	Maryland
I really don't know anything about it, so just plain old information would help.	Maryland
Demonstrate providing enough clean, low saline water at an economical price.	Arizona

c. Responses to the question: "What would help alleviate your concerns regarding the use of nontraditional water sources?"

Comments	State of residence
For produce- Food safety trumps all issues	Arizona
Would not consider using nontraditional water unless it becomes preferred by the buyers of my lettuce	Arizona
Acceptance throughout the food chain	Arizona
Food safety is of paramount concern on my farm.	Maryland
I hope this program pushes forward because fresh water will soon become the world's No.1 problem.	Maryland

customized strategies will be crucial to sustaining agricultural production across the varied regions of the United States and around the world.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2019.02.035.

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